

Comparing Ultraviolet Spectra against Calculations: Year 2 Results

Abstract

The five-year goal of this effort is to calculate high fidelity mid-UV spectra for individual stars and stellar systems for a wide range of ages, abundances, and abundance ratios. In this second year, the comparison of our calculations against observed high-resolution mid-UV spectra was extended to stars as metal-rich as the Sun, and to hotter and cooler stars, further improving the list of atomic line parameters used in the calculations. We also published the application of our calculations based on the earlier list of line parameters to the observed mid-UV and optical spectra of a mildly metal-poor globular cluster in the nearby Andromeda galaxy, Messier 31.

Overview

This is the Final Report for Year 2 of Contract No. NAS5-02052, covering the period May 2003 through May 2004. As described in the Final Report for Year 1, we began the second year with the ability to calculate mid-UV spectra which match high-resolution observations of mildly metal-poor stars of solar temperature, but not those of solar-metallicity stars or hotter stars. These are both potentially important contributors to the light of old stellar systems (e.g. O'Connell 1999). Consequently, in this second year, we extended our revisions of the list of atomic mid-UV line parameters by comparing our calculations against stronger-lined and both hotter and cooler stars. Peterson et al. (2003) also reported the application of our calculations based on the existing line list to a mildly metal-poor globular cluster in the nearby Andromeda galaxy (M31), discovering that blue horizontal branch stars are present in this system despite its one-third solar metallicity. Co-investigator Prof. Robert O'Connell was instrumental in assessing the properties of the M31 archival observational spectra. Principal investigator Dr. Ruth Peterson constructed combinations of the theoretical spectra to match these observations, while continuing the revision of the line list based on new STIS spectral observations.

Line List Revisions

As described in the Final Report for Year 1, we use the following procedure to revise the list of atomic-line parameters in the mid-UV that are input into our calculations. We download the initial line list from <http://kurucz.harvard.edu>, the website of Robert Kurucz, keeping only those lines from energy levels detected in the laboratory, and updating it with parameters from more recent laboratory measurements. We then run spectral calculations using the Kurucz program SYNTHE and the model atmospheres of Castelli et al. (1997), following the procedures of Peterson, Dorman, & Rood (2001). We calculate spectra for individual stars, generally re-determining their fundamental parameters beforehand from optical echelle spectra, and compare the theoretical spectra to high-resolution mid-UV observations. In Year 2 we obtained new Hubble Space Telescope Imaging Spectrograph (HST STIS) spectra for the standard F5IV-V star Procyon, the hot A1V star HD 72660, cool metal-poor star Groombridge 1830 (HD 103095) and the cool metal-rich star μ Leo (HD 85503). These comparisons enable us to extend the line-list revisions to match a wider range of spectral types.

Matching Globular-Cluster Spectra

Peterson et al. (2003) showed the ability of our calculations based on the previous line list to match the integrated-light spectrum of the M31 globular cluster G1. The color-magnitude diagram of Rich et al. (1996) indicated its iron abundance to be about one-fifth solar, $[\text{Fe}/\text{H}] = -0.7$, a metallicity suitable for our calculations, and hinted at the presence of blue horizontal branch stars, unexpected at that metallicity. Earlier Burstein et al. (1984) had pointed out the strong $\text{H}\beta$ (and CN) lines of this globular.

We proceeded to construct several possibly representative composite theoretical spectra to match this cluster. We simply coadded (with weights appropriate for a Milky-Way globular of this metallicity) the spectra we calculated for individual stars of this metallicity, including red giants, turnoff stars, main-sequence stars, and in some cases hot stars as well: either blue stragglers or blue horizontal branch stars. We downloaded the archival HST Faint Object Spectrograph (FOS) data described by Ponder et al. (1998). Following the recommendation of Prof. O'Connell, we checked the scattered-light for such data from the FOS documentation, and found it to be nil. After dereddening the observations and smoothing our theoretical composite spectra to the FOS resolution, we found a very fine match to all but CN in both the optical and mid-UV FOS observations, but only when blue horizontal branch stars were included. Because of the high flux level of the FOS spectra below 2500Å, which was not due to scattered light, we concluded that hot blue horizontal branch stars too faint to have been detected by Rich et al. (1996) are also present in the cluster.

The ability of our composite spectra to reproduce the observed spectra of G1 and to constrain its population is shown in the Figure 1. This is reproduced from Peterson et al. (2003, ©2003. The American Astronomical Society. All rights reserved. Printed in U.S.A.)

Figure 1 shows a sequence of comparisons of our theoretical spectral calculations (light line) versus the observed spectra (heavy line), offset vertically for clarity. One panel shows the mid-UV and the other, the optical; wavelengths in Å are given below each set of plots. The lowest plot is a comparison for an individual star, HD 106516, to illustrate how well the calculation for a single stellar model matches the observed spectra of a turnoff star. The remaining plots are comparisons against the FOS spectra of G1, dereddened by $E(B-V) = 0.06$. The lowest of these is the poorest fit; the composite spectrum contains no hot stellar components. The four plots above it explore various choices of the hot population. The best fit is shown at the top: it includes both hot and cool blue horizontal branch stars. The flux level below 2500Å is well matched, as are the Balmer lines. Only the CN band is not well reproduced.

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M31 G1 Mid-UV $E(B-V)=0.06$

Best Fit: Turnoff 6000K
Cool BHB + EHB $[Fe/H]=-0.8$

Cool BHB + EHB $[Fe/H]=-0.9$

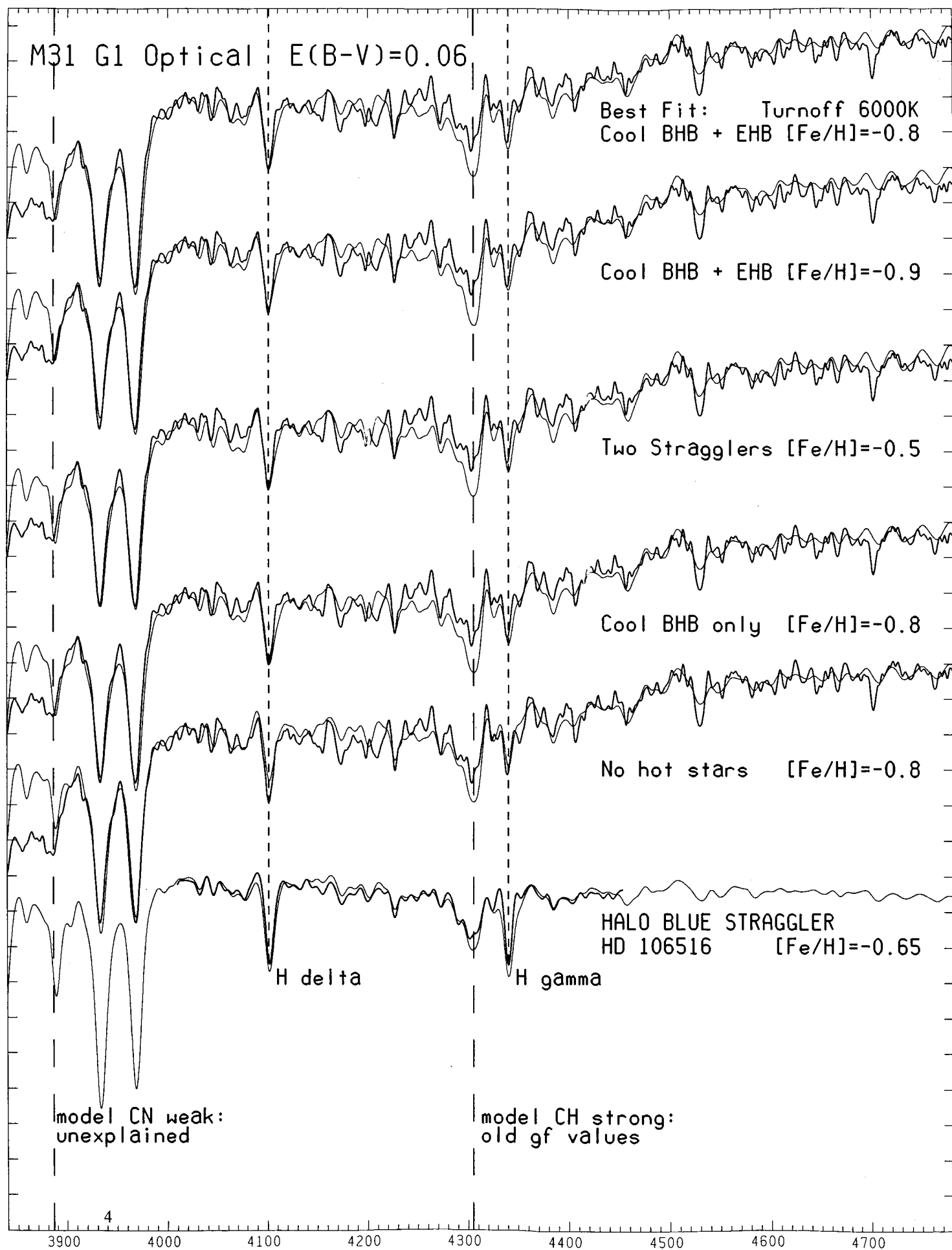
Two Stragglers $[Fe/H]=-0.5$

Cool BHB only $[Fe/H]=-0.8$

No hot stars $[Fe/H]=-0.8$

HD 106516 $[Fe/H]=-0.65$
HALO BLUE STRAGGLER

2300 2400 2500 2600 2700 2800 2900 3000 3100



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